A HELICOPTER'S LAST HOP

A helicopter was making a turn and slowing
to get into position to deposit a load trans-
ported at the end of a sling. The helicopter
crashed, killing the pilot, and demolishing
the helicopter. What happened?

A HELICOPTER'S LAST HOP (A)

Dr. Faber, a professional engineer, received a telephone call from an attorney, Mr. Pineberg, whom he had never met nor had worked with before. Mr. Pineberg told Dr. Faber that he was representing the widow, Mrs. Williams, of a helicopter pilot who had been killed when the helicopter he was operating crashed. Another attorney, Mr. Balsom, was representing Nine Points, the company that owned the helicopter. Two separate suits had been entered against the manufacturer, Spinmaker, but that the two attorneys were acting jointly, much as if there were a single suit against Spinmaker. Mr. Pineberg wanted to know if Dr. Faber could help as an expert witness in the suit against Spinmaker. Although Dr. Faber did not have extensive experience with aircraft in recent years, he had served in the Navy during World War II in aircraft maintenance. He had also worked as an expert witness in two cases involving helicopters. These did not focus on flight characteristics but on possible fatigue problems. His response was that if Mr. Pineberg would send him information, he would look at it and see if he felt qualified to help. Mr. Pineberg sent him the following:

A drilling company was on site at an altitude of about 8500 ft (2590 m). The weather was clear and cool on a morning in mid September. A helicopter had made one flight into the site to deliver the working crew. On a second flight, it had brought in a drilling skid at the end of a line. On the third flight at about 9:30 am the helicopter was delivering an air compressor. The first two flights were without incident. The load on the third trip was slightly greater than in the second but the weight of fuel was less, thus approximately compensating for the additional weight. The third flight, however, was fatal.

To quote an eyewitness: "We use a line which is 120 ft long to move components. The line attaches to the helicopter and has a hook on the end to pick up the components. Bill had just flown up to the location and was hovering above us, preparing to set the air compressor onto the skid. The compressor was about 100 feet in the air - the helicopter was approximately 220 feet up. Usually when the helicopter slows up into a location, there is a pitch change in the rotor blades. I heard the pitch change but then it was followed by a squealing noise. I then saw white-grey smoke coming from the motor followed by a burst of flame which shot out of the turbo unit. The flame was orange with blue. This all happened in a matter of 2 to 3 seconds. I was in the act of calling Bill to report the activity, but by then Bill knew the situation. After the flame shot out of the turbo, Bill dropped the load he was carrying. Bill was able to turn the helicopter to the north. On the way down he called "may day" twice before he hit the ground. Apparently Bill was trying to land the helicopter in a clearing but fell short of it by 40 yards. Some of the trees were anywhere

from 70 to 100 feet tall. After watching him go down, Tim, Glenn and I ran to the location of the crash. A small fire broke out by the turbo which Tim put out. I checked out Bill's condition which looked very bad. We decided not to move him, just to remove the debris away from his body. I couldn't get radio contact with anyone, so I hiked up a hill and called for help."

NATIONAL TRANSPORTATION SAFETY BOARD (NTSB) REPORT

Examination of body tissue and fluids showed no evidence of acidic, neutral or basic drugs, or ethyl alcohol in the pilot's blood or urine. No carbon monoxide was detected in blood containing 11.0 gm% hemoglobin.

External examination revealed that the transmission rotated freely. When the engine was rotated, noises were heard emanating from the clutch. When the clutch was removed, the engine turned more freely and the noise disappeared.

Examination of the inside of the exhaust diffuser revealed all turbine blades and stator vanes were burned off, leaving little nubs. The diffuser itself was completely coated with molten metal. The fuel filter was clean and free of debris. A small metallic chip was noted in the engine oil filter.

The reduction gear housing was removed with difficulty due to a bent fuel tube. Gear train continuity was established. The axial shaft was bent slightly.

There was no evidence in the compressor section of pre-impact damage to the axial compressor or impeller. Erosion was minimal. There was a rub mark on the impeller but evidence indicates this was caused by crushing of the counter and turbine casings at impact.

Metal shavings were noted in the diffuser section of the turbine section. These shavings showed no evidence of heat discoloration. Additionally, one of the six screws had backed out from the impeller (diffuser) labyrinth seal and had scored the back of the titanium centrifugal compressor. The other five screws were loose. The screw was twisted in its hole approximately 180°. The screw stem was opposite to the compressor's direction of rotation. The bore hole was elongated at the surface. Half of the screw head had been filed down.

All three turbine wheels and the second and third stage nozzle vanes were completely burned. The first nozzle vane was intact and not burned. There was a gray powdery substance on the vane leading edges. The rear bearing assembly, although galled, was unremarkable.

The sand filters were visually inspected. The filter was destroyed in the crash. The left filter's frame was buckled but the filter element was unremarkable. Both filters were cleaned 19.1 hours prior to the accident.

It was reported by a qualified airframe and powerplant mechanic that a strange noise was heard in the engine about 250 hours prior to the accident. Despite carefully listening for a similar noise,

it had not been heard again.

The speed governor and fuel pump were tested about three weeks after the accident. No abnormalities were found. The clutch was disassembled and examined. There was evidence of bearing-to-clutch rub. Although the front bearing contained little grease, there was no evidence of heat distress or discoloration. There was no evidence of malfunction/failure of either the starter-generator or the no. 5 bearing assembly.

Mr. Pineberg indicated that suit had been entered alleging a mechanically defective engine. The more detailed allegation was that the labryinth screw came loose, jammed against the impeller, slowing it enough to cause engine failure and burnout.

Spinmaker's position was that the crash was connected with excessive engine temperature having caused deterioration to the turbines, and as a result, a power reduction of the turboshaft power plant. Spinmaker asserted, after engine tear down and a thorough examination of the components, that no mechanical defectiveness could account, even partially, for the overtemperature. Spinmaker further asserted that failure was due to pilot error and to the conditions of the sand filters.

With regard to pilot error, Spinmaker believed that flight conditions at the moment of crash could have led the pilot to require an instantaneous power increase from an engine which had been degraded by numerous similar flights in altitude and outside temperature conditions largely exceeding normal values, i.e., around the thermal limits of the engine. There was a further belief that no power check had been carried out by the operator prior to this flight.

With regard to the sand filters, Spinmaker believed that the pressure variation of these filters had not been checked by Nine Points at any time since being put into service.

Spinmaker further stated that "the causes of this unfortunate crash cannot be traced back to some operating trouble on the ARTIST III C (No. 1099) engine. In particular, we blankly refute the assumption of abrupt engine rundown due to the loosening of a labyrinth securing screw. The consequences of this accidental loosening are known:

1. they are very limited as concerns alterations induced for other engine components
2. they have no effect whatsoever on the trouble free operation of the engine."

A HELICOPTER'S LAST HOP (B)

Dr. Faber read through this material and believed that he might possibly help Mr. Pineberg with his case. He also believed, however, that he really needed more information. If he could get some details about the engine and if he could (at least) get photographs of the labyrinth screws, labyrinth seal, and the titanium compressor, he believed he might be of substantial help. Accordingly, he telephoned Mr. Pineberg and discussed the items just mentioned above.

Mr. Pineberg indicated that he did have additional information and promised to send it to Dr. Faber. He sent several pages of information relative to the engine. He also had the engine shipped to Dr. Faber.

Dr. Faber worked through the information and examined the engine. He put together the following summary of information.

ARTIST III C ENGINE

This engine is a high speed, low torque engine. With a constant speed of 33,500 rpm, it has a thermal limit of 640 kW (858 shaft HP), derated to a working limit of 420 kW (562 shaft HP), at sea level. Constant speed is maintained by a governor which supplies additional fuel and air when the engine rotational speed decreases as load is increased. Spinmaker, the producer of the engine, is a corporation functioning in a European country.

There are six screws which are used to hold the aluminum (alloy unknown) labyrinth seal in position. The screws are placed every 60° around a bolt circle of 122 mm (4.8 in) diameter. The screws are steel (alloy unknown) 20 mm (0.79 in) long with a 5 mm (0.197 in) diameter. Two views of the screw are shown in Photographs 1 and 2. The head is 8 mm (0.315 in) in diameter with a height of 4 mm (0.157 in).

The aluminum seal plate is 15 mm (0.590 in) thick. The head of the screw fits in a recess which is 8 mm (0.315 in) in diameter and 4+mm (0.157+ in) deep. The plate to which this aluminum seal attaches is steel with a thickness of 5+ mm (0.197+ in). This steel plate is threaded. When the screw is fully inserted and tightened, the head is slightly recessed in the aluminum seal and the end of the screw is essentially flush with the surface of the steel plate. Two views of the recess and hole are shown in Photographs 3 and 4. A view of the bottom of the hole is shown in Photograph 5. It might be noted that when the underside of the screw head is flush with the top surface of the aluminum seal plate, the screw is engaged for just about one full turn. Alternatively, when the screw is in the hole but no thread is engaged, the head projects about 5.5 mm (0.216 in) above the aluminum seal plate.

Photographs 3 and 4 show the "bore hole elongation" indicated in the NTSB report. Photographs 1 and 2 show the screw head "filed down" as noted in the NTSB report. The scoring on the titanium impeller

(alloy unknown) noted in the NTSB report is shown in Photographs 6 and 7. The scoring is sufficiently pronounced that some small scratch lines are visible to the unaided eye.

A chart for operating characteristics of the ARTIST III C engine is given in Exhibit 1. The circled numbers indicate:

Area 1: Normal operation, less than 420 KW
Area 2: Maximum pitch
Area 3: Maximum thermal power

Photo 2. Labyrinth locking screw shown at 180°
from its orientation in Photo 1. Arrow
indicates region of deformed threads.
Note the head has been "ground" to a
"wedge" shape.

Photo 1. Labyrinth locking screw found loose in
failed helicopter engine. Arrow indi-
cates region of deformed threads.

- 7 -

Photo 4. Recessed hole in aluminum labyrinth seal.
Straight arrow indicates deformed region
in drilled recess and hole. Curved arrow
indicates direction of rotation of titan-
ium impeller relative to the aluminum seal.
Screw in Photos 1 and 2 came from this
hole. Note the deformation in this figure
is approximately diametrically opposite
that in Photo 3.

Photo 3. Recessed hole in aluminum labyrinth seal.
Straight arrow indicates deformed region
in drilled recess and hole. Curved arrow
indicates direction of rotation of ti-
tanium impeller relative to the aluminum
seal. Screw in Photos 1 and 2 came from
this hole.

Photo 6. View of face of titanium impeller show-
ing "rubbed" or "abraded" area with screw
from Photos 1 and 2. The width of the
abraded band is approximately the same
as the diameter of the screw head.

Photo 5. Bottom of hole in steel diffuser cover.
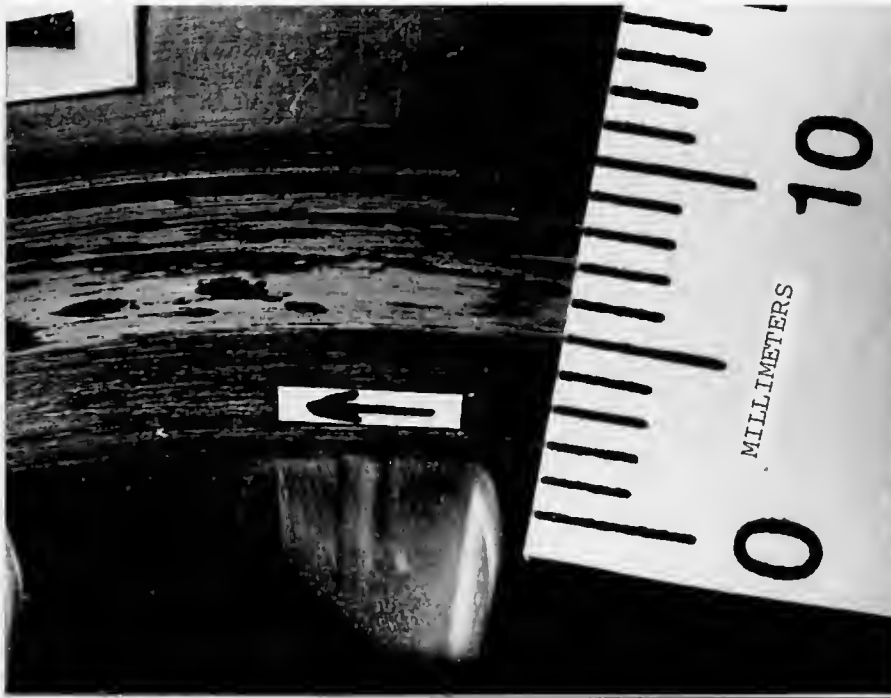Screw in Photos 1 and 2 came from this
hole.

- 9 -

Photo 7. Closer view (than in Photo 6) of a por-
tion of the abraded area on the face of
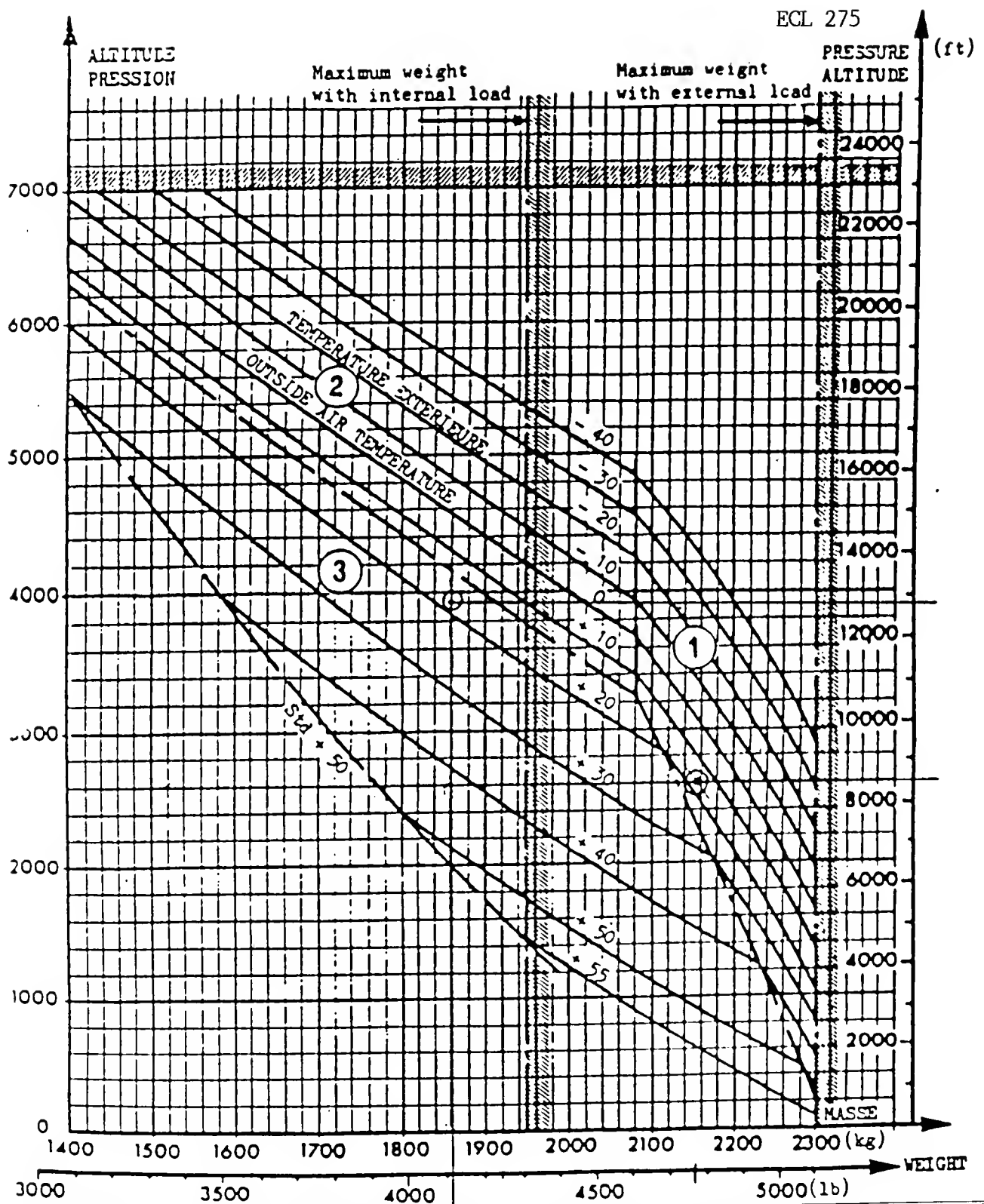the titanium impeller. Arrow indicates
direction of rotation.

Exhibit 1. Operating Characteristics of ARTIST III C Turbine Engine

A HELICOPTER'S LAST HOP (C)

Dr. Faber sent the summary given in Part B to Mr. Pineberg. He also told that it was his opinion that the engine failure had been caused by the loose labrynth screw. He also pointed out that he could be much firmer in his opinion if additional information were available, such as the alloys involved. Such information should allow a reasonable estimate of the friction force between the screw head and the titanium impeller. This, in turn, would allow an estimate of the torque imposed on the impeller by the screw. While an estimate could be made of the mass moment of inertia of the engine and the two rotors, manufacturer's information on this point would be much better. The combination of torque and mass moment of inertia would allow an estimate of speed reduction in the engine.

Dr. Faber also commented as follows:

All parties appear to agree about engine meltdown or burnout, presumably from too rich a fuel/air mixture. Whether this was too much fuel or too little air is not worth the effort to try to determine.

With regard to Spinmaker's assertion that the cause of the crash was pilot error and the condition of the sand filters:

(1) Pilot error is always a possibility. In this case, however, it seems to be of low probability. The pilot was in good health with no evidence of being under the influence of any drugs at the time of the crash. He had some 16 years (8500 flying hours) in helicopters. He had six years (2000 flying hours) in this specific type of helicopter in this general terrain. All of this experience had been without any significant incidents.

(2) The effect of the inlet air (sand) filters does not seem significant. They had been cleaned 18 to 20 hours earlier. There was no evidence of clogging upon examination, either immediately or several weeks later. In any event, clogging would have been a slow gradual effect, not a sudden event which could lead to a crash.

In effect, in Dr. Faber's opinion, the real question was whether or not the loose labyrinth screw rubbing on the impeller could have sufficient effect to cause engine failure and the crash.

In Dr. Faber's opinion, he believed this was the situation, but at this point he did not have sufficient evidence to provide strong support for his opinion. He believed he needed additional information.

A HELICOPTER'S LAST HOP (D)

As part of the discovery process, it developed that the NTSB made available information which had not been cited above.

The NTSB data included 23 documented cases in which labyrinth screws backed out of the aluminum seal and scored the titanium impeller. None of these cases, however, showed any evidence that the loose screws caused an engine to fail and cause a helicopter crash.

The NTSB data also noted that Spinmaker had issued a service bulletin some seven years earlier for the ARTIST II C engine. This bulletin had been initiated in response to a strong complaint from a military customer who had experienced problems with screw loosening. This bulletin also applied without change to the ARTIST III C engine. The bulletin is shown in Exhibit 2.

[The engine in this helicopter (Engine No. 1099) had been modified in accordance with this service bulletin. Photograph 8 shows the head of one screw in Engine No. 1099 after the crash. Photograph 9 shows the thread end of another screw in the same engine.]

About two months after the crash, Mr. Scott (the NTSB investigator) and Mr. Stone (a representative of Nine Points) went to the Spinmaker facilities to allow Spinmaker personnel to examine the engine parts and to witness a test demonstration of an ARTIST III C engine. Five of the labyrinth screws had been locked in keeping with Exhibit 2. The sixth was covered with paraffin. The expectation was that engine heat would melt the paraffin, allowing the screw to back out and contact the rotating impeller. The engine with a clutch, transmission, and main rotor blades was placed on a test stand enclosed by a steel-mesh fence. The engine was started several times and run at 10 minute intervals. Full power stabilized at 33,489 rpm. Mr. Scott applied rapid and full input to simulate a sudden power demand. Power dropped to a maximum of 33,370 rpm. On shutdown, a faint rubbing noise could be heard. When the engine was opened, the paraffin covered screw had backed out and the head was ground down.

About a month later, Spinmaker's Chief Airworthiness Engineer wrote to the FAA that: "This excessive power demand of the helicopter drive system lead to maximum fuel flow, rpm drop, air flow decrease and then overheat of the turbines up to the blade burning off."

About another month later (four months after the crash), Mr. Scott's superior wrote: "No internal cause of malfunctioning has been found (the loosening of a labyrinth screw which was observed during examination has been proved having no detrimental effect on the engine rotation)."

[About three weeks after this test, Spinmaker did further testing for one hour of operation with a pitch variation of 6° to 15° over a period of ten minutes and autorotation of 64 seconds. On shut-down, after the sixth start up, a seizure in the rotating assembly was detected. There is no evidence, however that this was reported to NTSB. This information was found during the discovery process.]

SPINMAKER'S INDEPENDENT EXPERT

Dr. Manhunt, a metallurgical/mechanical engineer, was retained by Spinmaker to perform additional work on its behalf. It was his summary opinion that the labyrinth screw did not jam against the impeller and any contact between the labyrinth screw and the impeller would not cause any significant reduction in engine speed. He measured the hardness of the aluminum ring as Rockwell E-53. The hardness of the screw was Rockwell C-30. He estimated the force required for the screw to deform the aluminum seal plate as seen in Photograph 3 as about 700 lb (3110 N).

He developed a test to simulate the interaction between the screw and impeller. An 18 in (45.7 cm diameter titanium plate (Ti-6Al-4V) was mounted in the chuck of a lathe. The plate was turned down to give a smooth machined surface similar to that on the impeller. The lathe was operated at its highest speed, about 1000 rpm. Labyrinth screws (identical to the one in question from Engine No. 1099) were individually pressed against the plate face with an axial load varying from light to nearly 50 lbs (222 N). The screw heads were worn. The lathe was not bothered by the torque created and continued to operate at rated speed. In his opinion, these tests demonstrated that the damage of the screw in question was likely produced by light contact between the screw and impeller and that, if such contact had no effect on a low horsepower lathe, it would have no effect on the helicopter engine.

FRONT LABYRINTH

Modified TU 133 - M 138

1. Purpose of modification

    To improve locking of sckrews securing front labyrinth to dif-
    fuser cover.

2. Description of modification (figure below)

    Locking of the six screws attaching labyrinth to cover was
    achieved by punching. This is improved by addtional locking on
    both sides:

    a - Head side: Metal from surrounding surface of plate is
        forced into both ends of the screw slots.

    b - Thread side: Metal of the screws is forced into two milled
        indentations on either side of the six drilling of the laby-
        rinth.

Note:

These locking precedures are carried out using a special tool made
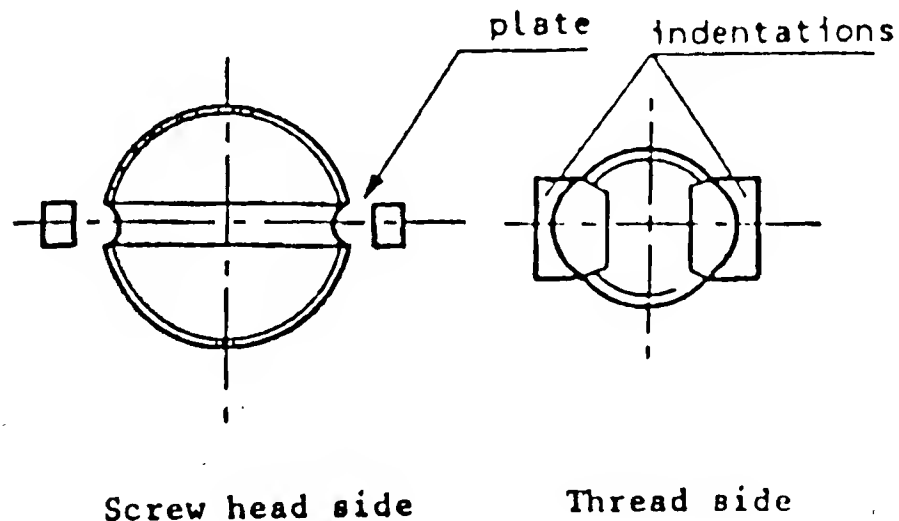up of two punches.

Screw head side   Thread side

EXHIBIT 2

Photo 8. View of head of one of the labyrinth locking screws in the failed engine. The slot in the head does not line up in the manner indicated in Exhibit 2.

Photo 9. View of bottom of one of the labyrinth locking screws in the failed engine. (Not the same screw as in Photo 8.) This appears to conform with Exhibit 2.

A HELICOPTER'S LAST HOP (E)

As noted in Part C, it was Dr. Faber's opinion that the friction from the contact between the screw and impeller face following wedging was more than sufficient to give a significant reduction in speed and lead to engine burnout.

Photographs 1 and 2 show regions on the screw in which the threads are deformed. Photograph 3 shows a region in the aluminum seal plate in which there is deformation, including thread impressions, in the recess for the screw head. Dr. Manhunt's aluminum hardness reading of Rockwell E-53 would indicate a yield strength of about 21 ksi (146 Mpa). Using the measured areas of deformation with this strength, Dr. Faber estimated that the force required to make this deformation was about 900 lb (4000 N). This force is essentially the friction force between the screw head and the impeller face. Knowing the bolt circle diameter, the torque on the impeller from the screw friction was calculated as 228 ft-lb (310 N-m). Using the mass moment of inertia of the engine and the two rotors [0.23 kg-m^2 (5.5 lb-ft^2), found in Spinmaker data during discovery], he calculated the decrease in rotational speed of the engine over 1 second of operation as given in Exhibit 3. Assuming the estimate of deformation force was in error by a factor of 2, that decrease in speed is also shown in Exhibit 3. He believed either loss of speed in that short a time was more than great enough to lead to engine burnout.

It was his opinion that Dr. Manhunt's lathe test did not provide a good simulation of the conditions in the engine as it did not provide an opportunity for wedging of the screw and was run at a much slower speed over a much longer time. It was his opinion that the screw head could not have been ground as shown in Photograph 2 if it had not been wedged in one position, rather than being free to rotate.

It is noted that both Photographs 3 and 4 show deformation of the aluminum seal plate. The two deformations, however, are approximately diametrically opposite. In Dr. Faber's opinion, the deformation shown in Photograph 3 was caused by wedging of the screw leading to engine failure. The deformation shown in Photograph 4, on the other hand, was caused by the screw being forced "backward" on impact of the helicopter with the ground. This is consistent with the indication in the NTSB report that the "screw stem was opposite to the compressor's direction of rotation."

SPEED OF ARTIST III C ENGINE
Speed at time indicated
for engine with 2 rotors
(Estimated)

Time Seconds	Engine Speed, rpm "Screw Torque," N-m	
	310	155
0.0	33,500	33,500
0.1	33,023	33,260
0.2	32,545	33,023
0.3	32,050	32,784
0.4	31,552	32,545
0.5	31,046	32,297
0.6	30,530	32.050
0.7	30,015	31,800
0.8	29,840	31,552
0.9	28,945	31,303
1.0	28,390	31,046

EXHIBIT 3

A HELICOPTER'S LAST HOP (F)

It is obvious that there was a strong difference of opinion as to whether or not the loose labyrinth screw could have caused failure in the engine. There was agreement, however, that the helicopter weight was about 2800 lb (1275 kg or 12,450 N). The weight of the air compressor on the sling was about 1300 lb (590 kg or 5780 N). The altitude at which the work was being performed was about 8500 ft (2590 m) with an ambient air temperature of 64 ^{o}F (18°C).

Mr. Boston, a senior engineer with Spinmaker, made the calculations shown in Exhibit 4. Mr. Boston drew the conclusion that Bill Williams, the pilot, had obviously operated outside the proper operating "envelope" of the engine. [He made no comment on the fact that this same helicopter had successfully made a similar run earlier the same day. Neither did he comment on the fact that another helicopter of the same model with an ARTIST III C engine was sent to the drilling site to continue the work. No difficulty was encountered with this second helicopter.]

Diagram Compressor explanation:

At local conditions the necessary power to maintain the ▮▮▮▮ at constant altitude above the drilling site is,

(A) 331 kw.

If helicopter arrives quickly the power is more impotant because the slinged compressor weight increases helicopter inertia.

In this case, with the load factor, the power is

(B) 420 Kw

27% INCREASE $\cdots$

17% INCREASE IN WT

$P_{ue_2} = P_{ue}\left(\frac{w_2}{w_1}\right)^{3/2}$

With a simultaneous right turn
(2 seconds) the above power increases at

© 512 Kw.

To point the above power on the
corrected compressor diagram of the
█████████████████████ it is necessary
to multiply the real power value by
the corrected factor:

$$\frac{1013}{730}\sqrt{\frac{288}{291}} = 1,3805$$
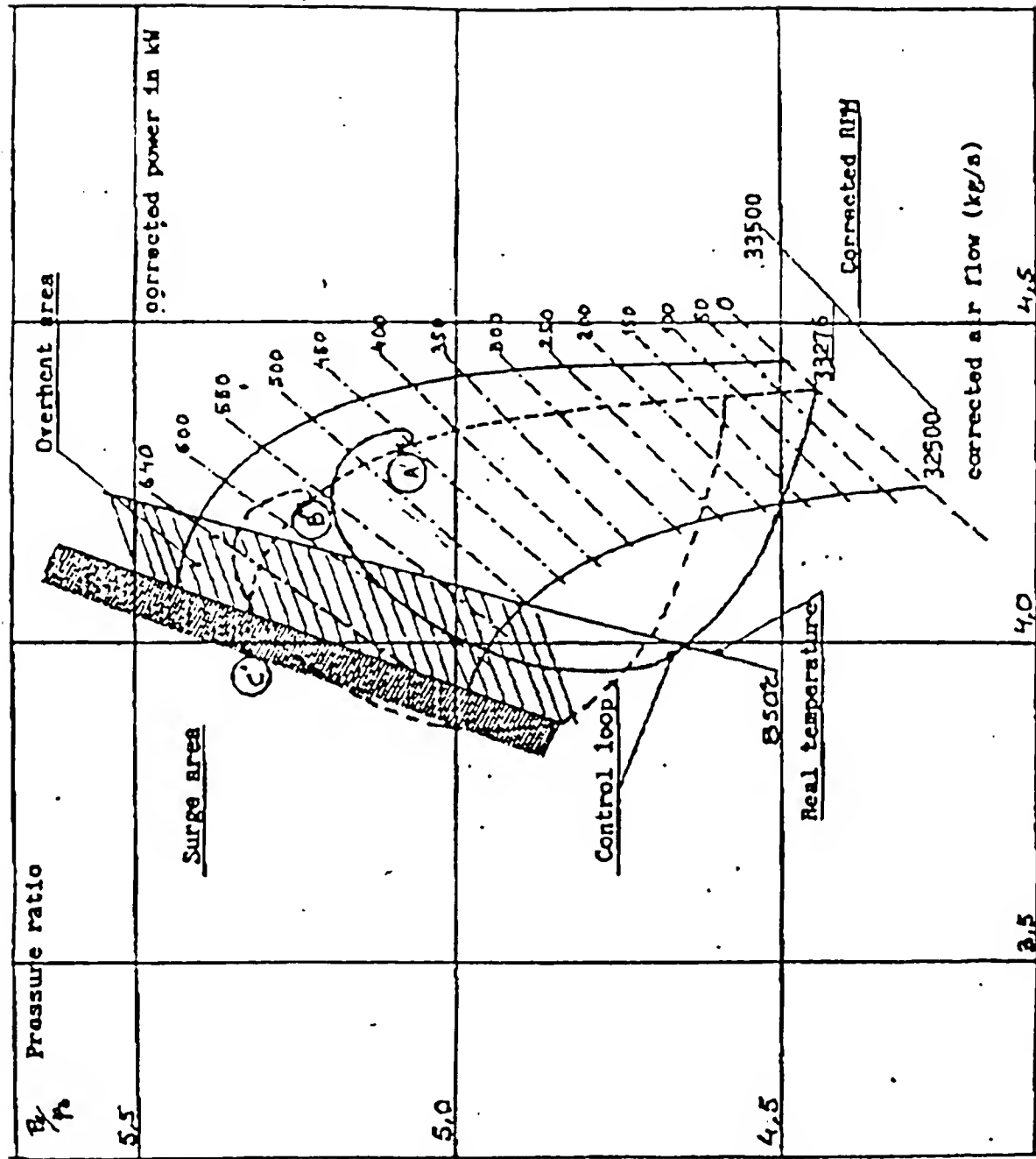
CORR FACTOR FOC S.L.
ISA CONDITION,

The corrected power values are :

Ⓐ 457 Kw

Ⓑ 580 Kw

© 707 Kw

The three above values are pointed on the
diagram

Performance chart relating "corrected" power, "corrected" speed, normal control loop, overheat region, and surge (burnout) region for the failed engine.

Exhibit 4, Page 3 of 3

A HELICOPTER'S LAST HOP (G)

Mr. Pineberg had retained a second independent expert, Mr. Piston, with particular expertise in helicopter operations. Mr. Piston made similar calculations but with different results. He agreed with Mr. Boston's first calculation of 331 kW (444 HP). He agreed with Mr. Boston's factor of 1.27 and his second calculation of 420 kW (563 HP). Mr. Piston disagreed with a "bank" factor of 1.22, which implies a bank angle of about 35°. Mr. Piston considered this highly unrealistic. In his opinion, a bank angle no greater than 20° was much more realistic, giving a load factor of about 1.06. His third calculation, therefore, was 443 kW (594 HP). He further disagreed with the use of the factor of 1.38 to correct for altitude as the initial calculation of 331 kW (444 HP) was at operating altitude. A comparison of the two sets of calculations is shown in Exhibit 5. When Mr. Piston plotted his data on the diagram in Exhibit 4 or on Exhibit 6 (a somewhat different version of the diagram in Exhibit 4), he concluded that the helicopter was operating within the proper "envelope" even though it was rather close to the limit.

Mr. Piston also considered the tests that Dr. Manhunt performed on the lathe. The rating of Dr. Manhunt's lathe was unknown. Assuming a 14 HP (10.5 N-m) lathe, Mr. Piston made calculations as shown in Photograph 10. In Dr. Manhunt's test, all of the torque [74 ft-lb (100 N-m)] (at 1000 rpm) was available to resist the effect of the screw. In the engine running under load, only 8 ft-lb (10.8 N-m) was available to resist the effect of the screw.

It was Mr. Piston's opinion that the labyrinth seal screw did indeed become loose and wedge in a position in which it rubbed on the impeller face. This created enough torque to severely overload the engine leading to burnout and the fatal crash.

ENGINE POWER CALCULATIONS

Defendant   Plaintiff

At local conditions, constant altitude, level flight

331 kW   331 kW

Arrival, slowing, starting to hover,
load factor 1.27

420 kW   420 kW

Simultaneous right turn, load factor
1.22   1.06
(35°) (20°)

512 kW   443 kW

Altitude correction
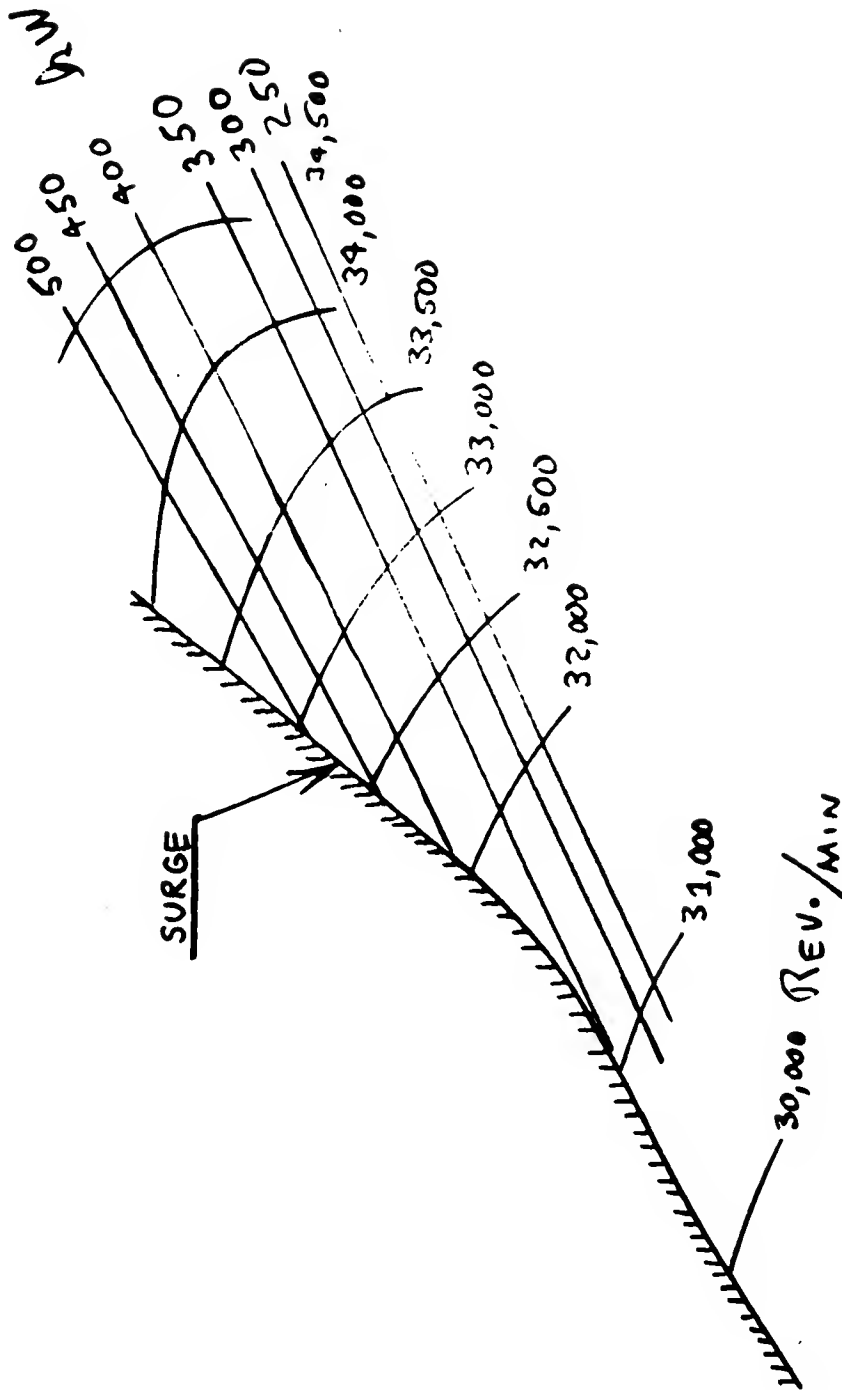1.38   none

707 kW   443 kW

Engine thermal limit   640 kW

Exhibit 5

At Altitude of 8500 ft.

Exhibit 6: Sectional performance chart showing power, speed, and surge region for the failed engine at an altitude of 8500 ft (2590 m).
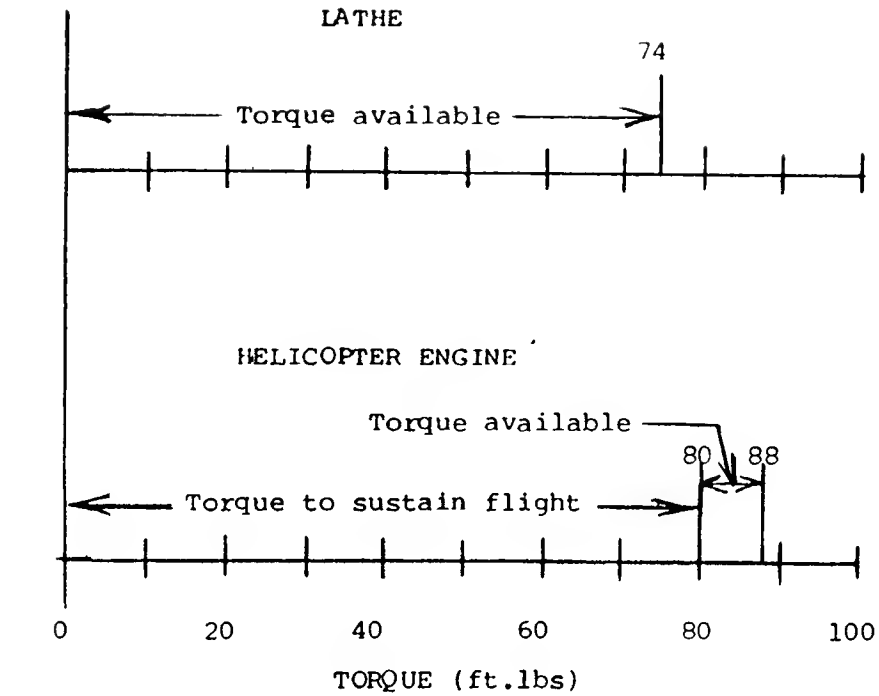
LATHE

74

Torque available

HELICOPTER ENGINE

Torque available

80 88

Torque to sustain flight

0   20   40   60   80   100

TORQUE (ft.lbs)

Photo 10. Comparison of torque available for inter-
action between a labyrinth screw and a ro-
tating titanium plate or impeller in the
case of a 10.5 kW (14 HP) lathe and the
failed helicopter engine.

A HELICOPTER'S LAST HOP

An instructor's note is not intended to tell an instructor how to use a given case or what aspects to emphasize. Rather, it is intended to hopefully provide some additional insight and some suggestions for focus. These suggestions may take the form of potential questions for students to work with and tangents which might well prove fruitful with a given class.

It is obvious that this case has a principal focus on the question of whether or not a labyrinth locking screw coming loose inside a constant speed turbine engine could lead to engine failure, burnout, and the ensuing crash of a helicopter. This focus alone implies questions relating to engine performance, flight characteristics of helicopters, positive locking of screws, development of simulated tests, and assumptions in making calculations. Overall, there is a question of products liability litigation and its interaction with engineering practice.

The instructor may think that there are too many segments in the case, as written. This viewpoint has some validity. The segmentation was done deliberately so that the instructor might have maximum flexibility in combining segments for class use.

Potential Questions;

Part A: One obvious approach is to have students take the position of Dr. Faber, summarizing what he/she knows, what he/she believes of the statements made, and what action he/she would take. The students might also be asked what kind of professional expertise would be appropriate for Dr. Faber to be qualified expert witness for Mr. Pineberg. [As a matter of fact, Dr. Faber is a "mechanical/metallurgical" engineer with considerable experience (both in industry and academia) in design of a variety of mechanical products and some 25 years experience as an expert witness. He has a BS degree in Mech. Eng. from WPI and an ScD in Metallurgy from MIT. He is also a Registered Professional Engineer. (One question might focus on the relative importance of the degrees and experience versus registration in terms of jury reaction.)]

Does this appear to be a highly singular event or could it be one of a series of incidents? Why?

Part B: This obviously supplies the student with much more information that he/she previously had. It certainly can be assumed that the 7 photographs and the engine characteritics (Ehibit 1) are valid data and not open to argument. Obviously, the interpretation of the photographs can be argued. In case there is misinterpretation, the deformed threads shown in Photo 1 coincide with the deformation shown in Photo 3. Presumably, the deformed threads shown in Photo 2 were made at the same time but there is no photographic evidence of the deformation near

the bottom of the hole drilled through the aluminum ring. One might
question how there can be two diametrically opposite deformations at
the top of the drilled hole as shown in Photos 3 and 4. One might ask
how the screw head became "wedge" shaped as shown in Photo 2. One
might also ask how an estimate could be made of the force required to
cause the deformations in the aluminum ring. How would one respond
to Spinmaker's claim (Pg. 4, Part A) that the crash was due to pilot
error? What effect does the fact the Spinmaker is not a US manufac-
turer have on litigation proceedings? Does is become easier or more
difficult? Does the student, in the role of Dr. Faber, have any opin-
ion at this point? If so, is it a strong or a weak opinion? Does the
student, as Dr. Faber, think he/she can help Mr. Pineberg? What addi-
tional information, if any, does the student believe he/she needs to
have a very strong opinion? Where would this information be obtained?

Part C: Does the student agree with Dr. Faber. If not, what are the
differences? What information, in addition to those items mentioned
by Dr. Faber, does the student believe that he/she needs?

Part D: Exhibit 2 is a service bulletin. Does this "fix" provide
a good locking mechanism? If the judgment is that this is not very
effective, what would be an effective locking mechanism? Can the
student propose more than one alternative? What is the judgement
regarding validity of the test conducted at Spinmaker facilities?
What is the reaction to the opinions stated by (1) Spinmaker's Chief
Airworthiness Engineer and (2) Mr. Scott's superior? [Pg. 13, para-
graphs 6 and 7] Does the student agree or disagree? Why? What is
the reaction to paragraph 8 on Pg. 13? What is the "discovery process"
and what role does it play in products liability litigation? Is Dr.
Manhunt's simulated test on a lathe have validity in the context of
the engine failure? Does the student agree, or disagree, with his
conclusion? Why? Of what value (or use) are the hardness measure-
ments cited? If these can be used to estimate the strengths of the - ·
aluminum ring and the steel screw, how would they be used and what
strengths are estimated?

Part E: Using Dr. Manhunt's hardness reading of Rockwell E-53 for
the aluminum ring, Dr. Faber checked through data in the Volume 2, 9th
Edition, ASM Metals Handbook and concluded that the yield strength
would be about 21 ksi (146 Mpa). [Presumably a 6061-T4 or 6063-T5
aluminum alloy.] He also measured the deformed areas in Photos 1 and
2. At the top of the screw this was about 0.137 in (3.48 mm) in length
over a screw diameter of 0.197 in (5.0 mm) or about 0.027 in^2 (17.4
mm^2). At the bottom of the screw this was about 0.079 in (2.0 mm) in
length over a screw diameter of 0.197 in (5.0 mm) or about 0.016 in^2
(10 mm^2). The estimated crushing force is the product of the area and
the yield strength. The radius from the axis of rotation is 2.24 in
(57 mm). The change in rotational speed can be estimated from
$M = \Delta I \alpha$. Assuming that the force on the screw to cause the deforma-

- 2 -

tion is the same as the friction force between the titanium impeller and the screw head, the student can be asked to make the calculations which would give Exhibit 3. Does the student have different assumptions (potentially better) to make similar calculations? Any comments on Dr. Faber's reaction to Dr. Manhunt's lathe test? Any comments on Dr. Faber's interpretation of Photo 2? Any comments on Dr. Faber's interpretation of the diametrically opposite deformations shown in Photos 3 and 4?

Part F: This section, in particular, offers an opportunity to look at the flight characteristics of the helicopter. There are, no doubt, many available sources of information. Two that were used were: (1) George H. Saunders, "Dynamics of Helicopter Flight," Wiley-Interscience and (2) R. W. Prouty, "Helicopter Aerodynamics," Spiral bound book, publisher unknown. Students can be asked to verify (or critize) Mr. Boston's calculations and conclusions.

Part G: Mr. Piston'c calculations and conclusions obviusly differ from those of Mr. Boston. Comments and/or constructive criticism from the students? Reaction to Mr. Piston's comments on Dr. Manhunt's lathe test and his interpretation? Any student suggestions on a better way?

Now that all the available information is in the hands of the students, one could ask what decision each would make if he/she were serving on a jury hearing this case. Is the plaintiff's allegation valid? Does the student judge that the plaintiff's case has been made with a preponderance of the evidenc, i.e., greater than 50%? ["Beyond a reasonable doubt" applies only in criminal cases, not a civil case such as this.] If Mr. Pineberg and Mr. Balsom have made their case, what award would the student juror recommend?

OUTCOME

The case went to trial in a Federal Court in April 1990. The jury returned a verdict in favor of the plaintiffs, awarding $690,000 to Mrs. Williams and the cost of the helicopter to Nine Points.

COMMENT

It was somewhat surprising that no question was raised with regard to the effectiveness of Spinmaker's service bulletin to "improve locking of screws securing front labyrinth to diffuser cover." It seems obvious it was not fully effective. Certainly the screw shown in Photographs 1 and 2 came loose. It appears that the screw shown in Photograph 8 had either not been properly staked or had broken loose. NTSB had data on 23 cases of loose screws. It is highly probable there were other situations not reported or disclosed to NTSB or the plaintiffs.
There appear to be at least four alternative methods of better

securing the screw:
1. Use a chemical locking compound. This may not be acceptable
    because of possible temperature effects.
2. Put the screws in in the opposite direction, i.e., head on the
    steel side and screw into the aluminum. There was sufficient
    room on the other side of the steel cover to do this.
3. Use screws in the original orientation but drill a small hole
    through the steel (or aluminum) and insert a wire acting as a
    "key" to resist screw loosening.
4. Use cap screws with a socket head (rather than slotted) in the
    original orientation. Use a longer screw with a jam nut. There
    was ample room on the other side of the steel cover for this.

        What is the student reation to the jury verdict? What is the stu-
dent reaction to the failure to put any focus on the effectiveness of
Exhibit 2 during the development of the litigation? What reaction,
in general, does the student have about the responsiveness (or lack
thereof) of Spinmaker?